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LOWER SNAKE RIVER COMPENSATION PLAN
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SAWTOOTH FISH HATCHERY VOLITIONAL RELEASE EXPERIMENT

A STOCKING METHOD TO REDUCE RESIDUAL STEELHEAD IN THE UPPER SALMON RIVER, IDAHO

Project Progress Report

January 1, 1996 — December 31, 1996

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By

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ABSTRACT

A volitional release technique was tested at Sawtooth Fish Hatchery, Idaho, to determine if in-hatchery emigration behavior of steelhead *Oncorhynchus mykiss* was indicative of seaward migration. Passive integrated transponder (PIT) tags were used to determine if steelhead that volitionally emigrated (Migrant Group) from raceways were interrogated at downstream dams at a higher rate than steelhead that displayed no in-hatchery emigration behavior (Nonmigrant Group) and steelhead that were not allowed to emigrate (Control Group). Tagged steelhead from each group were described using morphological data and visually classified as parr, transitional, or smolt.

Approximately 82% of the steelhead stocked into raceways at Sawtooth Fish Hatchery on March 28 emigrated volitionally by May 13. Males and females emigrated in equal proportions; the sex ratio of steelhead stocked on March 28 was not significantly ($P>0.05$) different than the sex ratio of nonmigrants sampled on May 13. Mean length and weight were not significantly ($P = 0.1829$) different between migrant and nonmigrant steelhead. Migrants had significantly ($P = 0.0001$) higher mean condition factor (K). Steelhead classified as smolts were significantly ($P \leq 0.05$) longer, heavier, and had lower mean condition factor than steelhead classified as transitional or parr. Steelhead classified as transitional were significantly ($P \leq 0.05$) longer and heavier than steelhead classified as parr, but condition factor was not significantly ($P > 0.05$) different. Precocial male steelhead were significantly ($P = 0.0170$) heavier and had significantly ($P < 0.0001$) higher mean condition factor than nonprecocial males; mean length was not significantly ($P = 0.2778$) different. Most of the precocial males were classified as transitional or parr. No precocial females were observed.

Steelhead tagged with PIT tags in the Migrant Group were interrogated at a significantly ($P \leq 0.05$) higher rate compared to PIT-tagged steelhead in the Nonmigrant and Control groups. Steelhead in the Control Group were interrogated at a significantly ($P \leq 0.05$) higher rate than steelhead in the Nonmigrant Group. Travel time to Lower Granite Dam, Washington, was not significantly ($P > 0.05$) different among PIT-tagged steelhead in the Migrant, Nonmigrant, and Control groups. Steelhead classified as smolts had significantly ($P \leq 0.05$) higher interrogation rates than steelhead classified as either transitional or parr. Transitional steelhead had significantly ($P \leq 0.05$) higher interrogation rates than parr.

Nearly 18% (9,851) of the steelhead stocked into treatment raceways did not emigrate to lower raceways. At the conclusion of the study, all steelhead, including nonmigrant steelhead, were forced into the Salmon River. We estimated that a minimum of 34.8% (3,430) of steelhead in the Nonmigrant Group were smolts and migrated seaward and that a maximum of 65.2% (6,421) of the steelhead became stream residents (residuals).

In-hatchery emigration behavior of steelhead was indicative of seaward migration. The technique we tested shows promise as a way to effectively reduce the number of residual hatchery steelhead entering the Salmon River, especially if the efficiency of the technique can be increased by manipulating environmental factors in the hatchery to enhance volitional emigration behavior.

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INTRODUCTION

The Idaho Department of Fish and Game (IDFG), in cooperation with the United States Fish and Wildlife Service, stocks summer steelhead *Oncorhynchus mykiss* at the Sawtooth Fish Hatchery weir and other locations in the upper Salmon River under the Lower Snake River Compensation Plan (LSRCP). The LSRCP is a hatchery program that was authorized by the Water Resources Development Act of 1976 to compensate for fish and wildlife losses caused by the construction and operation of four dams on the lower Snake River (Ice Harbor, Lower Monumental, Little Goose, and Lower Granite dams) (LSRCP 1992).

In 1991, the National Marine Fisheries Service (NMFS) listed Snake River sockeye salmon *O. nerka* as endangered under the Endangered Species Act (ESA) and in 1992 listed Snake River spring/summer and fall chinook salmon *O. tshawytscha* as threatened (NMFS 1995). Listed sockeye salmon and spring/summer chinook salmon inhabit the upper Salmon River drainage where hatchery steelhead are stocked annually. Stocking hatchery steelhead in waters inhabited by ESA-listed species warrants evaluation to ensure negative interactions such as competition for food and space, predation (Miller 1958, Bachman 1984, Vincent 1987), and the spread of disease (Ratliff 1981) are minimized. Hatchery steelhead that elect to become stream residents (residuals), rather than emigrate to the ocean, are of special concern.

Viola and Schuck (1995) developed a stocking technique that was effective at reducing the number of hatchery steelhead residuals released into the Tucannon River, Washington. Their stocking technique consisted of three major components: 1) acclimation—steelhead were acclimated in a pond prior to release, 2) volitional release—steelhead were permitted to volitionally emigrate from the pond, and 3) selective detainment—steelhead that failed to emigrate were detained. Viola and Shuck (1995) reported that the proportion of residual steelhead released into the Tucannon River when using this technique (3.1%) was significantly lower than the proportion which resulted from a direct stream release (14.0%), where all steelhead were released directly from a truck into the stream.

The purpose of this study was to develop a fish stocking technique for use at Sawtooth Fish Hatchery that would reduce the number of residual hatchery steelhead released into the upper Salmon River. We tested a modified version of Viola and Schuck's technique using the same theme: steelhead emigration is a responsive, natural behavior associated with parr-smolt transformation that directs true smolts to emigrate, thereby separating themselves from steelhead that are not physiologically ready to emigrate. In our study all steelhead that did not volitionally emigrate from hatchery raceways by the end of the study were force-released into the Salmon River to determine migration success of nonmigrants. If this technique is successful at separating true smolts from residuals, all nonmigrants would be detained for catch-out fisheries.

The goal of this study was to develop a fish stocking method that would reduce the number of residual hatchery steelhead entering the Salmon River and thereby minimize potential interactions between hatchery steelhead and native species. Specific objectives were to:

1) Determine if in-hatchery volitional emigration of steelhead is indicative of seaward migration.

2) Describe the utility of this volitional release technique to minimize residual steelhead in the Salmon River.

3) Describe migrant and nonmigrant steelhead.

4) Describe steelhead classified as parr, transitional, and smolts.

5) Describe precocial steelhead.

METHODS

A total of 87,233 Sawtooth A-stock steelhead (brood year 1995) were used for this study. Steelhead were reared for 10 months at Hagerman National Fish Hatchery, Idaho, before being transported to Sawtooth Fish Hatchery, Idaho, on March 28, 1996. Steelhead were stocked into raceways 1A (30,088), 3A (28,742), and 4A (28,403). Steelhead in raceway 1A were designated the Control Group; steelhead in raceways 3A and 4A were replicate treatment groups.

Raceways were 58.9 m (193 ft) long, 3.7 m (12 ft) wide, and 0.7 m (2.3 ft) deep. Water flow was set at 3,216 liters/minute (L/min) (830 gal/min) in each raceway. Raceways were constructed in a paired, flow-through series allowing water to flow through the A-section raceways before being reused in the B-section raceways. Screens were placed at the lower end of raceways 1A, 3A, and 4A to prevent steelhead from entering the respective B-section raceway. Steelhead were hand-fed a maintenance ration of commercial fish food (Rangen 1/8" Trout Diet) throughout the study.

Baseline data were collected on steelhead in each raceway on March 28, 1996. Steelhead were sampled by taking a dip net grab-sample from three different raceway locations (i.e., one each—top, middle, bottom). One hundred steelhead were selected, euthanized, measured (fork length, mm), weighed (g), classified by stage of development (parr, transitional, smolt) and maturation stage (precocious, nonprecocious), and sexed. Steelhead were classified as either parr, transitional, or smolt based on the presence or absence of parr marks and skin coloration (Ewing et al. 1984; Viola and Schuck 1995). Steelhead classified as smolts were silver in coloration and had very faint or nonexistent parr marks. Parr were dark in coloration and had very distinct parr marks. Transitional steelhead had characteristics of both smolts and parr and were defined as silver in coloration with distinct parr marks. Steelhead with enlarged gonads were classified as precocious.

On April 2, 1996 (six days after the steelhead were stocked), screens at the lower end of raceways 3A and 4A were removed to allow steelhead to volitionally emigrate to raceways 3B and 4B, respectively (Figure 1). Raceways 3B and 4B were equipped with screens at the lower end to prevent steelhead from entering the Salmon River. In addition, one water retention board (dam board), which measured 10.2 cm (4 in) in height, was removed from raceways 3A and 4A. The screen and dam board in raceway 1A (Control Group) were not removed. At this time, water flow was increased to 3,953 L/min (1,020 gal/min) in all raceways.

Steelhead that emigrated to B-section raceways during this study were designated migrants. Steelhead that did not emigrate to B-section raceways by May 13, the termination date of the study, were designated nonmigrants. Hereafter, methods described for migrants pertain to both raceways, 3B and 4B, unless specified; methods described for nonmigrants pertain to both raceways, 3A and 4A, unless specified. We estimated the number of steelhead that emigrated from raceways 3A and 4A by conducting a pound count (fish per pound multiplied by total weight of fish in pounds) of the migrants in raceways 3B and 4B.

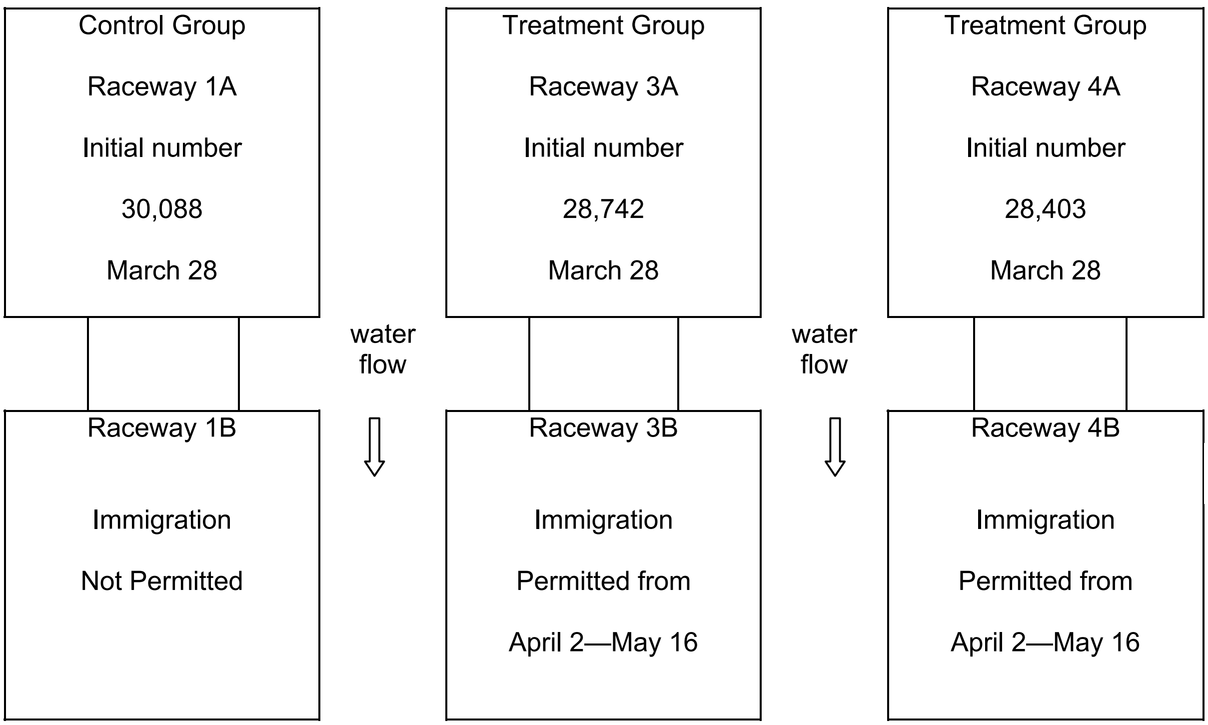

Figure 1. Study design details, raceway layout, and initial number of steelhead in the control and treatment raceways for the 1996 Sawtooth Fish Hatchery Volitional Release Experiment.

On April 10, 17, and 24 and May 1 and 8, migrants were enumerated (by raceway), sampled, and divided into two equal groups. Sampling procedures and data collection methods were as described above. Half of the migrants enumerated on each of the above dates were detained in the respective B-section raceway until the end of the study. These steelhead were defined as the Migrant Group and are the focus of this report. The other half of the migrants were released into the Salmon River one day after they were enumerated. Some of these steelhead were tagged with passive integrated transponder (PIT) tags (Prentice et al. 1990) to evaluate the effects of time-at-release on emigration success and emigration timing. These results will be presented in a separate report.

On April 10 and 24 and May 1, 8, and 13, raceways 3A and 4A were sampled to determine if the initial sex ratio had changed due to emigration. Sampling procedures and data collection were as described above. Viola and Schuck (1995) reported that the sex ratio of steelhead in Curl Lake acclimation pond, Washington, changed from 1:1 (male:female) at the start of the study to 4:1 following one month of volitional emigration.

Steelhead that emigrated to raceways 3B and 4B from May 8-13 were enumerated and added to the migrant group of the respective raceway. On May 13, screens were installed in the A-section raceways to prevent further emigration. At this time the steelhead left in raceways 3A and 4A were designated the Nonmigrant Group and enumerated, by raceway, using the pound count method. On May 13, steelhead in the Nonmigrant (raceways 3A and 4A), Migrant (raceways 3B and 4B), and Control (raceway 1A) groups were sampled as described above.

On May 14, 200 steelhead from each raceway (1A, 3A, 4A, 3B, and 4B) were randomly selected, anesthetized with tricaine methanesulfonate (MS-222), measured for fork length (mm), weighed (g), classified by stage of development, and tagged with PIT tags. Morphological data (e.g., length, weight, precocity) for each tagged steelhead were stored in computer files (PIT tag files). Precocial steelhead were identified by the presence of milt. Tagged steelhead were returned to a screened-off raceway section to facilitate collecting and documenting tagging mortality. All steelhead, including PIT-tagged fish, were forced into the Salmon River on May 16, 1996. All PIT tag files were submitted to the Columbia River Basin PIT Tag Information System (PTAGIS) (Pacific States Marine Fisheries Commission 1998).

Data Analyses

Two sets of data were collected and analyzed. The first data set, Sex Composition Data, was collected from steelhead euthanized during the study. These data were used to: 1) relate morphological characteristics to sex; 2) determine if the initial sex ratio of steelhead in raceways 3A and 4A changed as a result of in-hatchery emigration; 3) describe steelhead in the Migrant, Nonmigrant, and Control groups; 4) describe steelhead classified as parr, transitional, and smolt; and 5) describe precocial steelhead. The second data set, PIT Tag Data, was collected from steelhead tagged with PIT tags. These data were used to: 1) determine if steelhead in the Migrant Group were interrogated at downstream dams at a higher rate than steelhead in the Nonmigrant and Control groups; 2) compare the amount of time (i.e., travel time) it takes steelhead from the three groups to reach Lower Granite Dam, Washington, (the first dam encountered on the Snake River); and 3) describe steelhead interrogated at downstream dams.

All data were analyzed using SYSTAT (SYSTAT 1996) software. Probability values ≤ 0.05 were considered significant. Data for continuous variables were checked for normality before statistical analyses. Normally distributed data were tested using analysis of variance (ANOVA) or a two-sample t-test. If ANOVA was used, Bonferroni's post hoc test was used to separate means. Continuous data not normally distributed were tested using the Kruskal-Wallis test; Bonferroni's adjustment was used to identify significant differences (Kirby 1993).

Sex Composition Data

Initial (March 28) morphological data from raceways 1A, 3A, and 4A were used to estimate mean length, weight, and condition factor ($K = \text{weight (g)}/\text{length}^3\ \text{(mm)} \times 100{,}000$). Analysis of variance was used to test for significant differences among raceways and Bonferroni's post hoc test was used to separate means. Initial sample data were also used to estimate the sex ratio, the proportion of precocial males, and the proportion of steelhead for each developmental stage in raceways 1A, 3A, and 4A. Chi-square analysis was used to determine if the initial sex ratio of raceways 1A, 3A, and 4A was different.

The percentage of steelhead that emigrated from raceways 3A and 4A was calculated by dividing the estimated number of steelhead that emigrated by the number of steelhead available to emigrate (i.e., initial number stocked minus mortality and fish sacrificed for sampling), multiplied by 100. To determine if emigration altered the sex ratio of a population, we tested the initial (March 28) sex ratio data from raceways 3A and 4A against the final (May 13) sex ratio data of the respective raceway for independence using Chi-square analysis with the Yates correction for continuity (Zar 1984). In addition, sex ratio data collected from raceways 3A and 4A throughout the study were tested, by raceway, using Chi-square analysis.

Morphological data collected on May 13 were used to characterize steelhead in the Nonmigrant (raceway 3A and 4A—data pooled) and Migrant (raceways 3B and 4B—data pooled) groups. Mean length, weight, and condition factor of migrant and nonmigrant steelhead were compared among raceways and between groups for significant differences (ANOVA); Bonferroni's Post hoc test was used to separate means. Data collected on May 13 were used to estimate the proportion of males, the proportion of precocial males, and the proportion of steelhead in each developmental stage for each group (Control, Migrant, and Nonmigrant).

Morphological data collected from all steelhead sampled throughout this study were used to estimate length, weight, and condition factor of steelhead classified as parr, transitional, or smolt. Mean length, weight, and condition factor of parr, transitionals, and smolts were compared for significant differences (ANOVA); Bonferroni's post hoc test was used to separate means.

Morphological data collected from all male steelhead sampled throughout this study were used to estimate mean length, weight, and condition factor of precocial and nonprecocial male steelhead. A two-sample t-test was used to compare mean length, weight, and condition factor of precocial and nonprecocial male steelhead.

PIT Tag Data

Passive integrated transponder tags were used to evaluate downstream juvenile emigration. Interrogation rates of PIT-tagged juvenile salmonids at Columbia and Snake river dams serve as a minimum survival index because: 1) an unknown number of PIT-tagged fish that die in the hatchery may go undetected, although we scan the dead fish; 2) not all fish pass through detectors; 3) some PIT tags fail or are lost between tagging and arrival at interrogation sites; 4) some fish arrive while interrogation equipment is not being operated; and 5) mortality occurs between dams.

We used PIT tags to determine if steelhead behavior (i.e., in-hatchery volitional emigration) was indicative of seaward migration. Following the emigration period, randomly selected steelhead from the Migrant, Nonmigrant, and Control groups were tagged with PIT tags and released. We contacted PTAGIS in November 1996 to obtain interrogation results for PIT-tagged fish. The percentage of steelhead interrogated at downstream dams was calculated for each raceway and group by dividing the total number of unique interrogations at Lower Granite, Little Goose, Lower Monumental, and McNary dams by the number of steelhead released with PIT tags, multiplied by 100.

Chi-square analysis with the Yates correction for continuity was used to detect significant differences in interrogation rates between fish in replicate raceways, by group (e.g., raceway 3A vs. raceway 4A). Chi-square analysis was also used to test for differences in the interrogation rates of PIT-tagged steelhead in the Nonmigrant, Migrant, and Control groups; a Tukey-type multiple comparison was used to detect significant differences between groups (Zar 1984). Chi-square analysis was used to test the interrogation rates of steelhead classified as parr, transitional, or smolt; a Tukey-type multiple comparison was used to detect significant differences between developmental stages. The percentage of smolts, transitionals, and parr interrogated at downstream dams was calculated, by developmental stage, by dividing the number interrogated by the number of tagged steelhead released, multiplied by 100.

For the Migrant, Nonmigrant, and Control groups, we calculated the mean length, weight, and condition factor of PIT-tagged steelhead interrogated and not interrogated, at downstream dams. For each group, a two-sample t-test was used to test for differences in length, weight, and condition factor by interrogation status (i.e., interrogated vs. noninterrogated). Steelhead interrogated at downstream hydroelectric projects were not remeasured; morphological data collected at the time of tagging were used in the analyses.

Median travel time to Lower Granite Dam was calculated for PIT-tagged steelhead in each raceway. The Kruskal-Wallis test was used to test for significant differences in travel time (to Lower Granite Dam) among raceways.

On May 16, all steelhead, including PIT-tagged fish, were forced into the Salmon River. This procedure differed from the technique used by Viola and Shuck (1995); they detained all steelhead that failed to emigrate. We estimated the minimum number of “true smolts” that would have been sacrificed had we detained all nonmigrants by multiplying the number of steelhead left in each raceway (based on pound counts) by the PIT tag interrogation rate of tagged steelhead in the respective raceways. We estimated the maximum number of “residual” steelhead in each raceway by subtracting the estimated number of “true smolts” from the total number of nonmigrants left in each raceway.

RESULTS

Sex Composition Data

On March 28, mean length and condition factor of steelhead in raceways 1A, 3A, and 4A were significantly different; mean weight was not significantly ($P = 0.2339$) different (Table 1). Sex ratios of steelhead in raceways 1A, 3A, and 4A were not significantly ($\chi^2 = 1.69$, $P = 0.4304$) different at the start of the study (Table 2). Precocity rates of male steelhead, sampled on March 28, from raceways 1A, 3A, and 4A were 2.3%, 4.4%, and 1.9%, respectively. Table 2 shows the initial proportion of steelhead classified as parr, transitional, and smolts for each raceway.

A total of 86.6% of all the steelhead in raceway 3A (24,459 fish) and 77.5% of all the steelhead in raceway 4A (21,635 fish) emigrated to the respective B-section raceway (Figure 2). Weekly emigration totals for raceways 3A and 4A are shown in Table 3. The sex ratio of steelhead in raceways 3A and 4A, tested independently, did not change during the course of this study (Raceway 3A—$\chi^2 = 5.01$, df = 5, $P = 0.4142$; Raceway 4A—$\chi^2 = 1.69$, df = 5, $P = 0.9005$) (Table 4). The percentage of smolts in raceways 3A and 4A changed from approximately 50% on March 28 to about 85% on May 13 (Table 2). The percentage of smolts in the control raceway (1A) changed from 34% on March 28 to 98% on May 13.

On May 13 steelhead in raceways 1A, 3A, 3B, 4A, and 4B were not significantly different in mean length or weight ($P = 0.5597$; $P = 0.1537$, respectively) (Table 1). Mean condition factor of steelhead varied among raceways (Table 1). Mean length was not significantly ($P = 0.3178$) different between steelhead in the Migrant (raceways 3A and 4A pooled), Nonmigrant (raceways 3B and 4B pooled) and Control groups (Table 1). Mean weight and mean condition factor of steelhead in the Migrant, Nonmigrant, and Control groups were significantly different ($P = 0.0353$; $P < 0.001$, respectively) (Table 1). Although the overall test for mean weight was significant, Bonferroni's post hoc test failed to detect significant differences among groups. Mean condition factor of steelhead in the Nonmigrant Group was significantly greater than steelhead in the Control Group; mean condition factor of steelhead in the Migrant Group was not significantly different than the mean condition factor of steelhead in the Nonmigrant or Control groups (Table 1).

Table 1. Mean length (FL, mm) weight (g), and condition factor (K) of juvenile steelhead sampled at Sawtooth Fish Hatchery during the initial (March 28) and final (May 13) sample periods. Means are followed by a hyphen and the standard deviation. Dashed lines separate post hoc comparisons. Means followed by the same letter indicates a significant difference (P ≤0.05) among raceways or groups within a sample period.

Raceway Number	Group	Sample Period/Date	n	Mean Length	Mean Weight	Mean Condition
		Overall P-value		*P = 0.0340*	*P = 0.2339*	*P = 0.0022*
1A	Control All Fish	Initial 03/28	100	191.0-25.5 A	82.2-30.4	1.14-0.07 AB
3A	Treatment All Fish	Initial 03/28	100	198.0-19.8 A	88.6-26.7	1.11-0.07 A
4A	Treatment All Fish	Initial 03/28	100	196.7-24.2 B	88.4-32.6	1.11-0.06 B
		Overall P-value		*P = 0.5597*	*P = 0.1537*	*P <0.0001*
1A	Control	Final 05/13	100	197.1-18.8	75.3-20.4	0.96-0.05 A
3A	Nonmigrant	Final 05/13	98	197.4-21.7	77.5-23.9	0.98-0.06 B
4A	Nonmigrant	Final 05/13	98	197.0-22.8	77.2-24.5	0.97-0.07 C
3B	Migrant	Final 05/13	98	201.2-17.9	81.8-20.7	0.98-0.06 A
4B	Migrant	Final 05/13	100	198.8-18.8	81.9-23.4	1.02-0.06 ABC
		Overall P-value		*P = 0.3178*	*P = 0.0353*[a]	*P <0.0001*
1A	Control	Final 05/13	196	197.1-18.8	75.3-20.4	0.96-0.05 A
3A,4A	Nonmigrant	Final 05/13	198	197.2-22.2	77.7-24.2	0.98-0.06 A
3B,4B	Migrant	Final 05/13	100	200.0-18.3	81.8-24.2	1.00-0.06 AB

[a] Bonferroni's post hoc test failed to detect significant (P ≤0.05) differences.

Table 2. Sex ratio (males:females) of juvenile steelhead and the percentage of steelhead classified as parr, transitional, or smolt during the initial (March 28) and final (May 13) sample periods at Sawtooth Fish Hatchery. Dashed lines separate chi-square analyses. Sex ratio data followed by the same letter indicates a significant difference (P ≤0.05).

Raceway Number	Group	Sample Period/Date	n	Sex Ratio M:F	Percent Parr	Percent Trans	Percent Smolt
				χ^2 = *1.69, P = 0.4304*			
1A	Control All Fish	Initial 03/28	100	43:57 A	5.0	61.0	34.0
3A	Treatment All Fish	Initial 03/28	100	46:54 B	0.0	47.0	53.0
4A	Treatment All Fish	Initial 03/28	100	52:48 C	1.0	48.0	51.0
				χ^2 = *0.02, P = 0.8875*			
3A	All Fish	Initial 03/28	100	46:54 A	0.0	47.0	53.0
3A	Nonmigrant	Final 05/13	98	51:49 B	1.0	14.0	85.0
				χ^2 = *0.32, P = 0.5693*			
4A	All Fish	Initial 03/28	100	52:48 A	1.0	48.0	51.0
4A	Nonmigrant	Final 05/13	98	58:42 B	3.0	16.0	81.0

Table 3. Accounting and disposition of steelhead used in the 1996 Sawtooth Volitional Release Experiment. Emigration rates were calculated by dividing the number of fish that emigrated by the number of fish available to emigrate, multiplied by 100. The number of fish available to emigrate was calculated by subtracting the number of fish that died (mortality) and the number of fish sacrificed before May 13, from the initial number stocked.

		Control	Treatment		
Accounting Documentation	**Date**	**Raceway 1A**	**Raceways 3A and 3B**	**Raceways 4A and 4B**	**Raceways Combined**
Initial number stocked into A-section	3/28/99	30,088	28,742	28,403	57,145
Mortality A-section	—	252	0	0	0
Fish sacrificed in A-section prior to May 13	—	100	500	500	1,000
Weekly emigration from A-section:	04/10/96	0	7,530	6,752	14,282
	04/17/96	0	1,144	1,271	2,415
	04/24/96	0	1,282	1,128	2,410
	05/01/96	0	5,856	4,325	10,181
	05/08/96	0	2,659	2,296	4,955
	05/13/96	0	5,988	5,863	11,851
Total fish immigration to B-section[a]		0	24,459	21,635	46,094
Fish available to emigrate from A-section raceways prior to May 13[a]	—	0	28,242	27,903	56,145
Fish in A-section on May 13[a]	—	29,736	3,783	6,268	10,051
Fish sacrificed in A-section on May 13	—	100	100	100	200
Fish sacrificed in B-section on May 13	—	0	100	100	200
Fish released from A-section on May 16	—	29,636	3,682	6,168	9,851
Percent of fish that emigrated to B-section	—	0	86.6	77.5	82.1
Percent of fish that did not emigrated to B-section	—	100	13.4	22.5	17.9

[a] denotes the numbers used to calculate emigration rates

Table 4. Weekly steelhead emigration from raceways 3A and 4A during the 1996 Sawtooth Fish Hatchery Volitional Release Experiment. Sex ratio data were collected on steelhead that did not emigrate to determine if emigration affected the sex ratio. A double asterisk (**) indicates that emigration was not permitted. A single asterisk (*) indicates that sex ratio data were not collected. Sex ratio data followed by the same letter indicates significant differences (P ≤0.05) between sample dates.

	Fish Emigration From		Sex Ratio (males:females)	
Sample Date	**Raceway 3A**	**Raceway 4A**	**Raceway 3A**	**Raceway 4A**
			χ^2 = 5.01, P = 0.4142	*χ^2 = 1.61, P = 0.9005*
3/28/96	**	**	46:54 A	52:48 A
4/03/96	**	**	*	*
4/10/96	7,530	6,752	53:47 B	54:46 B
4/17/96	1,144	1,271	*	*
4/24/96	1,282	1,128	42:58 C	50:50 C
5/01/96	5,856	4,325	50:50 D	53:47 D
5/08/96	2,659	2,296	56:44 E	51:49 E
5/13/96	5,988	5,863	51:49 F	58:42 F
Total Fish Emigration	**24,459**	**21,635**		

Over all sampling dates, there were significant differences in mean length (P <0.0001), weight (P <0.0001), and condition factor (P <0.0001) among steelhead classified as parr, transitional, and smolts (Table 5). Steelhead classified as smolts were significantly (P ≤0.05) longer, heavier, and had lower mean condition factor than steelhead classified as transitional or parr. Steelhead classified as transitional were significantly (P ≤0.05) longer and heavier than steelhead classified as parr, but mean condition factor was not significantly (P >0.05) different (Table 5).

A total of 1,600 steelhead were sacrificed during this experiment (Table 3). Fifty-one percent (810) of the steelhead sampled were males and 4.8% (39) of these males were precocious. A total of 790 females were sacrificed; none of the females were precocious. Most of the precocial males were classified as transitional (24) or parr (12), only three of the precocial steelhead were classified as smolts. Precocial males were significantly (P = 0.0170) heavier and had significantly (P <0.0001) higher mean condition factor than nonprecocial males; length was not significantly (P = 0.2778) different. On May 13, the last day of the study, 19 precocial males were observed in the sample from the Nonmigrant Group (raceway 3A = 5, raceway 4A = 14); none were observed in the samples from the Control and Migrant groups.

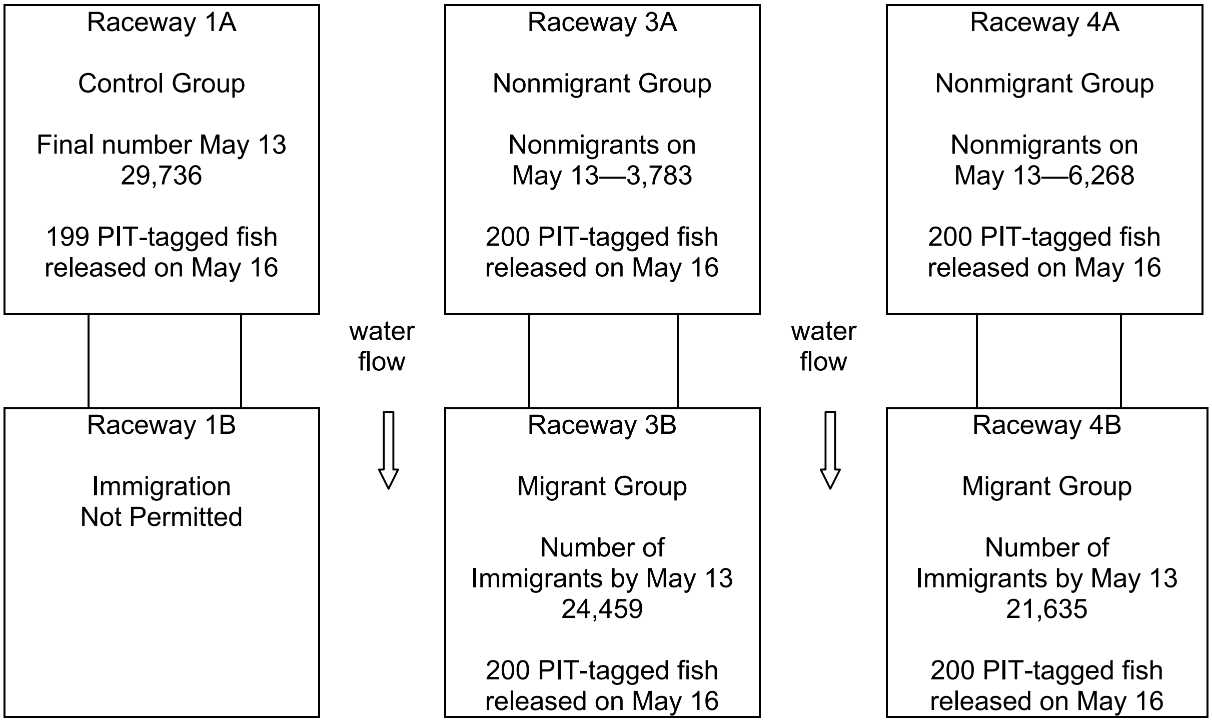

Figure 2. Number of steelhead in the Control, Migrant, and Nonmigrant groups at the conclusion of the 1996 Sawtooth Fish Hatchery Volitional Release Experiment. All fish, including PIT-tagged fish, were forced into the Salmon River on May 16. Note the number of fish released for each group was less than reported above due to fish being sacrificed for data collection.

Table 5. Mean length (FL, mm), weight (g), and condition factor (K) of steelhead classified as smolt, transitional, or parr. Data from all sample periods and from all raceways were used in the analysis. Means are followed by a hyphen and the standard deviation (sd). Means followed by the same letter, within a column, indicates a significant difference (P ≤0.05) among means.

	Length		**Weight**		**Condition Factor**	
Group	**n**	**Mean – sd**	**n**	**Mean – sd**	**n**	**Mean – sd**
Overall P-value		*P <0.0001*		*P <0.0001*		*P <0.0001*
Smolt	1235	200.3 – 19.1 A	1141	84.5 – 24.0 A	1141	1.02 – 0.08 AB
Transitional	323	183.7 – 20.7 A	317	69.4 – 23.8 A	317	1.08 – 0.07 B
Parr	31	165.1 – 34.8 A	30	55.5 – 33.2 A	30	1.11 – 0.09 A

PIT Tag Data

Interrogation rates at Snake River dams of nonmigrants in raceways 3A and 4A were 29.5% and 38.5%, respectively (Table 6). Interrogation rates of migrants in raceways 3B and 4B were 49.0% and 53.5%, respectively. Steelhead in the Control Group had an interrogation rate of 40.7%. Interrogation rates of migrants and nonmigrants in replicate raceways (e.g., raceway 3B vs. raceway 4B) were homogeneous (Table 7); these data were pooled by group. Steelhead in the Migrant, Nonmigrant, and Control groups were interrogated at significantly ($\chi^2 =$ 24.6, P <0.001) different rates. Steelhead in the Migrant Group were interrogated at a significantly (P $\leq$0.05) higher rate than steelhead in the Nonmigrant and Control groups (Table 8). Steelhead in the Control Group were interrogated at a significantly (P $\leq$0.05) higher rate than steelhead in the Nonmigrant Group (Table 8). Travel time to Lower Granite Dam was not significantly (P >0.2147) different among steelhead in the Migrant, Nonmigrant, and Control groups.

Interrogation rates of steelhead classified as smolts, transitionals, or parr were significantly different (χ^2 = 70.5, P <0.001). Smolts were interrogated at a significantly (P $\leq$0.05) higher rate than transitional steelhead or parr (Table 9). Transitional steelhead were interrogated at a significantly (P $\leq$0.05) higher rate than parr (Table 9). Travel time to Lower Granite Dam was significantly (P = 0.0350) greater for transitional steelhead as compared to smolts. Parr were excluded from this analysis because no PIT-tagged parr were interrogated at Lower Granite Dam.

Table 6. Number of unique interrogations of PIT-tagged steelhead at Lower Granite, Little Goose, Lower Monumental, and McNary dams during the 1996 migration period. Fish were tagged to evaluate emigration timing and emigration success of steelhead classified as migrants and nonmigrants in the 1996 volitional release study at Sawtooth Fish Hatchery. Median travel time is to Lower Granite Dam (GRJ).

Raceway Number	Group	Date Released	Number Released	Number Interrogated	Percent Interrogated	Median Travel Time (Days) To GRJ
1A	Control	05/16	199	81	40.7	11.4
3A	Nonmigrant	05/16	200	59	29.5	14.4
4A	Nonmigrant	05/16	200	77	38.5	14.8
3B	Migrant	05/16	200	98	49.0	14.4
4B	Migrant	05/16	200	107	53.5	12.8

Table 7. Chi-square analyses used to determine if PIT tag data from steelhead in raceways 3 and 4 were homogeneous for each group (i.e., migrant and nonmigrant) and to test if interrogation (detection) rate was independent of migrational status. Smolts classified as migrants emigrated to a lower raceway; steelhead classified as nonmigrants failed to emigrate from an upper raceway.

Group	Raceway	Number of Observed Detected	Number of Expected Detected	Number of Observed Undetected	Number of Expected Undetected	DF	χ^2	($\alpha = 0.05$)
Migrant	3B	98	78.5	102	121.5	1	15.140	
Nonmigrant	3A	59	78.5	141	121.5			
Migrant	4B	107	92	93	108	1	8.464	
Nonmigrant	4A	77	92	123	108			
Migrant	3,4 (B)	205	170.5	195	229.5	1	24.634	
Nonmigrant	3,4 (A)	136	170.5	264	229.5			
Total of chi-squares						2	23.604	
Pooled chi-square (chi-square of totals)						1	24.634	
Heterogeneity chi-square (24.206 - 24.353)						1	1.03	Fail to Reject H_0^1
Pooled chi-square with Yates correction for continuity						1	24.634	Reject H_0

H_0: Detection of smolts is independent of migrational status.
H_a: Detection of smolts is not independent of migrational status.

H_0^1: The samples from the two experimental raceways are homogeneous (i.e., can pool samples).
H_a^1: The samples from the two experimental raceways are not homogeneous (i.e., cannot pool samples).

Table 8. Interrogation rates of PIT-tagged steelhead in the Migrant, Nonmigrant, and Control groups. Steelhead classified as migrants emigrated to a lower raceway; steelhead classified as nonmigrants did not emigrate from an upper raceway. A total of 999 tagged steelhead were released on May 16, 1996 as part of the Sawtooth Fish Hatchery Volitional Release Experiment. Chi-square analysis revealed that interrogation rates were significantly ($\chi^2 = 24.6$, $P < 0.001$) different among groups. A Tukey-type multiple comparison was used to identify significant differences between groups. Interrogation rates followed by the same letter indicate a significant ($P \leq 0.05$) difference among groups.

Group Designation	Number Released	Number Interrogated	Percent Interrogated
Migrant	400	205	51.3 A
Control	199	81	40.7 B
Nonmigrant	400	136	34.0 C

Table 9. Interrogation rates of PIT-tagged steelhead classified as parr, transitional, or smolt. Steelhead were part of the Sawtooth Fish Hatchery Volitional Release Experiment. A total of 999 tagged steelhead were released on May 16, 1996. Thirty-five PIT-tagged steelhead were not classified by developmental stage. Chi-square analysis revealed that interrogation rates were significantly ($\chi^2 = 70.5$, $P < 0.001$) different among developmental stages. A Tukey-type multiple comparison was used to identify significant differences between stages. Interrogation rates followed by the same letter indicate a significant ($P \leq 0.05$) difference among developmental stages.

Developmental Stage	Number Released	Number Interrogated	Percent Interrogated
Smolt	451	242	54.0 A
Transitional	455	158	34.7 B
Parr	58	2	3.4 C

A total of 1,000 steelhead were tagged with PIT tags for this study. One fish from the Control Group died after tagging. Only 964 of the 999 steelhead were classified by developmental state at the time of tagging. Disregarding migrational status and raceway designation, 54% of all smolts, 34.7% of all transitionals, and 3.4% of all parr were interrogated at downstream dams. Of the 58 steelhead classified as parr and tagged with PIT tags, only two were interrogated at downstream dams.

Within each group, steelhead interrogated at downstream dams were significantly ($P \leq 0.05$) longer and heavier than steelhead that were not interrogated at the dams (Table 10). For the Control and Nonmigrant groups, steelhead that were not interrogated at downstream dams had significantly higher mean condition factor as compared to steelhead that were interrogated. Mean condition factor was not significantly different between interrogated and noninterrogated steelhead in the Migrant Group.

Approximately 18% (9,851 fish) of the steelhead in raceways 3A (3,683) and 4A (6,168) did not volitionally emigrate to a lower raceway. Interrogation rates of PIT-tagged steelhead in raceways 3A and 4A were 29.5% and 38.0%, respectively. Using the interrogation rate of tagged steelhead in each raceway, we estimated that a minimum of 3,430 of the nonmigrants in raceways 3A and 4A (3A-1,086; 4A-2,344) were smolts and emigrated downstream (Table 11). Conversely, we estimated that a maximum of 6,421 of the nonmigrants in raceways 3A and 4A (3A-2,597; 4A-3,824) became residuals.

Table 10. Mean length, weight, and condition factor (K) of PIT-tagged steelhead in each group by interrogation status. Steelhead interrogated (detected) at downstream dams were compared to steelhead that were not interrogated (not detected). Fish interrogated at downstream dams were not remeasured; morphological data collected at the time of tagging were used in the analyses. Sample sizes (n) are in parentheses following the mean.

	Mean Length (FL, mm)			Mean Weight (g)			Mean Condition Factor (K)		
Group	Detected	Not Detected	P value	Detected	Not Detected	P value	Detected	Not Detected	P value
Control	206 (81)	190 (118)	0.0001	81 (81)	67 (117)	0.0008	0.89 (81)	0.92 (117)	0.0011
Migrant	210 (205)	199 (195)	0.0000	86 (197)	73 (191)	0.0000	0.89 (197)	0.87 (191)	0.1381
Nonmigrant	201 (136)	185 (264)	0.0000	77 (136)	64 (263)	0.0000	0.92 (136)	0.95 (263)	0.0000

Table 11. Estimated numbers of smolts and residuals in the population of nonmigrant steelhead remaining in raceways 3A and 4A at the end of the study (May 13). The number of smolts was estimated by multiplying the interrogation rate of PIT-tagged steelhead in raceways 3A and 4A by the number of fish left in each raceway. The number of residuals in each raceway was estimated by multiplying the number of fish left in each raceway by the proportion of steelhead not interrogated at downstream dams.

Raceway	Number Nonmigrants	Interrogation Rate (%)	Estimated Smolts	Estimated Residuals
3A	3,683	29.5	1,086	2,597
4A	6,168	38.0	2,344	3,824
Total	9,851	—	3,430	6,421

DISCUSSION

Viola and Shuck (1995) developed a fish release technique that significantly reduced the number of residual hatchery steelhead released into the Tucannon River, Washington. In the present study we adapted a modified version of their technique at Sawtooth Fish Hatchery and used PIT tags to contrast the migrational performance of steelhead that actively emigrated (Migrant Group) from raceways to steelhead that displayed no in-hatchery emigration behavior (Nonmigrant Group) and steelhead that were not allowed to emigrate (Control Group). We found that PIT-tagged migrants were interrogated at downstream dams at a significantly higher rate than nonmigrants. Our results concur with Schuck et al. (1995) who conducted a similar experiment at Curl Lake acclimation pond in Washington and reported that far more PIT-tagged migrants were interrogated at downstream locations as compared to nonmigrants (33.2% vs. 3.5%, respectively). We also found that PIT-tagged steelhead in the Migrant Group were interrogated at a significantly higher rate than PIT-tagged steelhead in the Control Group. This provides additional support to the hypothesis that in-hatchery emigration behavior is indicative of seaward migration because a random sample of fish from the Control Group would likely contain fewer “true smolts” than the Migrant Group. Travel time to Lower Granite Dam, the first dam encountered on the Snake River, was not significantly different between the three groups (Migrants, Nonmigrants, and Control). This indicates that emigration conditions were similar for all three groups, which further strengthens our thesis.

Our study, along with the research conducted by Schuck et al. (1995), confirm that volitional migratory movement of hatchery steelhead during the emigration period represents a true seaward migration and not just random movement. Passive integrated transponder tags and the PTAGIS system are primarily responsible for this discovery. Early researchers such as Ewing et al. (1984) and Wagner (1968) had no way of directly linking the volitional movement of individual fish to seaward migration and had to assume this association when they measured physiological and morphological characteristics of migrant and nonmigrant steelhead.

In this study, 17.9% (9,851) of the steelhead in the A-section treatment raceways did not volitionally emigrate by May 13. Ewing et al. (1984) reported that 33% and 46% of steelhead at Cole Rivers Hatchery, Oregon, failed to volitionally emigrate from raceways by the middle of June in 1981 and 1982, respectively. Shuck et al. (1995) reported that 23% and 14.8% of the steelhead acclimated in Curl Lake acclimation pond did not emigrate in 1993 and 1994, respectively. The proportion of steelhead that emigrated in our study suggests that steelhead acclimated in raceways responded similarly to steelhead acclimated in Curl Lake acclimation pond.

The sex ratio of steelhead in raceways 3A and 4A did not change as a result of emigration. Viola and Shuck (1995) reported that the male:female ratio in Curl Lake acclimation pond changed from 1:1 at the start of the experiment to 4:1 at its conclusion. They reported that 78% of the steelhead that failed to emigrate from Curl Lake acclimation pond were males and that 24% of these males were precocious. We found that 54.5% of the steelhead remaining in raceways 3A and 4A at the end of the study were males and that 17.4% of these males were precocious.

Many studies have examined the morphological characteristics of steelhead in an effort to identify indices related to the parr-smolt transformation and seaward migration (Chrisp and Bjornn 1978; Evenson and Ewing 1992; Ewing et al. 1984; Seelbach 1987; Schuck et al. 1995; Tipping and Byrne 1996; Viola and Shuck 1995; Wagner et. al. 1963; Ward and Slaney 1990; Ward et al. 1989). Several researchers have reported that the condition factor of steelhead generally decreased during parr-smolt transformation (Ewing et al. 1984; Tipping and Byrne 1996; Wagner 1968). However, Chrisp and Bjornn (1978) failed to see a consistent decline in condition factor for the different groups of steelhead they studied. Migrating steelhead were generally larger than nonmigrants (Chrisp and Bjornn 1978; Ewing et al. 1984; Tipping et al. 1995; Wagner et al. 1963; Ward and Slaney 1990) and had lower condition factors (Ewing et al. 1984; Schuck et al. 1995).

We found that migrants and nonmigrants were not significantly different in length or weight (steelhead sampled on May 13), but migrants had significantly higher condition factor. We are uncertain why our results differed from those reported by other researchers. We support our findings with the following information. The release method tested in this study was not 100% effective at separating residuals from true smolts, as evidenced by a 33.8% interrogation rate (overall) for PIT-tagged steelhead in the Nonmigrant Group. Moreover, 83.2% of the nonmigrant steelhead sampled on May 13 were classified as smolts (Table 2). In contrast, 99.5% of the steelhead in the Migrant Group sampled on May 13 were classified as smolts. These results describe a rather vague distinction between migrants and nonmigrants and support our findings that length and weight were not different between the two groups.

In our study, smolts were significantly longer and heavier than steelhead classified as transitional or parr. Ewing et al. (1984) also classified steelhead based on visual developmental characteristics and reported that steelhead classified as smolts or partial smolts (synonymous to our transitional stage) were significantly longer than steelhead classified as parr. Schuck et al. (1995) reported that smolts were longer and heavier than steelhead classified as transitional or parr. We found that smolts were interrogated at a significantly higher rate than transitional or parr. Shuck et al. (1995) also reported that smolts were interrogated at downstream dams at a significantly higher rate compared to steelhead classified as transitional. In addition, they reported that no precocial steelhead, or steelhead classified as parr, were interrogated at any downstream location. We tagged 59 parr with PIT tags, and only two were interrogated at downstream dams.

We did not observe a change in the sex ratio of the nonmigrants as reported by Viola and Shuck (1995) and cannot explain why, but we offer the following contrasts as possibilities. Viola and Shuck stocked steelhead into a true "pond" in late February, and steelhead were on station approximately one month before they were allowed to emigrate. For our study, steelhead were not stocked into raceways at Sawtooth Fish Hatchery until late March and were only on station one week before they were allowed to emigrate. Steelhead used in our study were transported from 15°C water at Hagerman National Fish Hatchery to 3.7°C water at Sawtooth Fish Hatchery (range 3.7°C-12.6°C). Steelhead studied by Viola and Shuck (1995) were transferred from Lyons Ferry Fish Hatchery, Washington (water temperature = 10°C), to Curl Lake where the water temperature ranged from 3.3°C-7.7°C (Mike Sutterfield, Washington Department of Fish and Wildlife, personal communication). Sawtooth Fish Hatchery is located 1,976 meters (6,480 feet) above sea level (Hutchison [sic] 1993); Curl Lake is located approximately 732 meters (2,400 feet) above sea level (Mike Sutterfield, Washington Department of Fish and Wildlife, personal communication). Steelhead in the Washington study were not fed once emigration started and the pond water level was lowered; steelhead at Sawtooth Fish Hatchery were fed a maintenance ration throughout the experiment. Tipping and Byrne (1996) reported that restricted feeding of steelhead juveniles at Lake Aberdeen Hatchery, Washington, lowered condition factors and appeared to enhance emigration rates. The water level of Curl Lake was lowered throughout the emigration period; we changed flows only once at the beginning of the emigration period. Viola and Schuck (1995) believed that pond volume, pond flow, and duration of acclimation were critical to the success of their fish stocking method.

Viola and Schuck (1995) listed the benefits of their stocking method as reduced levels of predation, disease transmission, and competition to native species by hatchery steelhead. They listed the main disadvantage as the loss of potential genetic resources that nonmigrants could contribute to future generations; in their study, nonmigrants were retained and used in a catch-out fishery.

In the present study, 17.9% (9,851 fish) of the steelhead in raceways 3A and 4A failed to emigrate. If all nonmigrants were retained and used in a catch-out fishery, we estimated that a maximum of 6,452 residuals would have been prevented from entering the Salmon River. Conversely, this action would have prevented a minimum of 3,399 true smolts from being released into the Salmon River. Managers must carefully consider all of the associated costs and benefits of this stocking technique before it is fully implemented and all nonmigrants are detained for catch-out fisheries.

Finally, we found that in-hatchery emigration behavior in steelhead is indicative of seaward migration. The technique we tested shows promise as a way to effectively reduce the number of residual hatchery steelhead entering the Salmon River. A major drawback of the method was the lack of efficiency in separating residuals from true smolts. It may be possible to enhance the migratory behavior of steelhead, and thus increase the efficiency of the technique, by manipulating the acclimation period, water flow, feeding regimen, water temperature, turbidity, or some other aspect of the rearing environment. Another study following the same methodology is planned for 1997.

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